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THE AIRBORNE LASER AND THE FUTURE OF THEATER MISSILE DEFENSE

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14. ABSTRACT
The theater ballistic missile (TBM) problem encountered in the Persian Gulf War revealed an alarming deficiency in US defenses. This paper takes a brief look at the major theater missile defense (TMD) systems in use and under development by the US today. Second, it focuses on the performance of the Army?s Patriot defense system in the Gulf War. Finally, the paper fulfills its main purpose of offering an in-depth look at the development of the Airborne Laser (ABL) and how it should fit into an overall national structure for TMD. The paper concludes that Patriot performance in the Gulf war was unsatisfactory, not just because of system flaws, but because of the concept of point defense itself. The ABL provides a unique solution to collateral damage inherent in point defense concepts. In addition, the ABL can provide advanced warning to other theater defense systems in the event of a mass launch which could overtax the ABL?s capabilities. The paper offers several recommendations for the future direction of TMD. First, phase out point defense completely and channel those funds into development of the other TMD systems which minimize collateral damage to the assets they are intended to protect. Second, expedite development of the ABL as the first line of TMD, backed up by longrange theater systems. Third, continue to develop true theater defense systems; that is, systems which have a range of hundreds of kilometers such as the Navy?s Aegis and the Army?s THAAD systems, preventing TBMs from getting close to their intended target.

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The views expressed in this academic research paper are those of the author and do not reflect the official policy or position of the US government or the Department of Defense.

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Preface

Having worked as Branch Chief in Airborne Laser (ABL) technology development for a year and a half before coming to Air Command and Staff College, I was naturally interested in the field of theater ballistic missile (TBM) defense. I began my research project with a desire to "champion the cause" of the ABL, but my horizons broadened as the research progressed and I developed a deeper appreciation for the larger picture of the TBM problem.

I discovered that the scope of the problem of theater missiles calls for a joint approach. One service simply cannot handle the entire threat by itself. The problem is too big, threatening every aspect of land, sea, and air assets, and each service's perspective is too limited to deal with the problem single handedly. Also I became convinced of the inability of point defense systems such as Patriot to deal with TBMs effectively, for reasons expounded upon in the paper. This purpose of this paper is therefore not to "peddle" one form of TMD at the expense of another, but rather an attempt to focus the increasingly limited defense dollars on the most promising systems to counter the TBM threat.

I would like to thank a number of people for their help and support in compiling this paper. First, thanks go out to my number one fan—my wife, Doreen. Without her understanding and our children's cooperation while "Daddy was studying," this project would have been much tougher to complete.

The staff and the Air University Library were especially helpful in locating the various sources of information used in this paper. Their patience and willingness to help made them a delight to work with.

The people in the ABL Technology Division at Phillips Laboratory, Kirtland Air Force Base, NM, deserve thanks as well. Their hard work and fine research have contributed immeasurably, not just to this paper, but to the future defense of the nation. Dr. Paul Merritt was especially helpful in providing details of laser destruction of TBMs.

Finally I want to thank Maj. Diane Fischer, my Faculty Research Advisor. Her enthusiasm and practical help enabled me to choose a relevant topic keep focused on it through completion.

Abstract

The theater ballistic missile (TBM) problem encountered in the Persian Gulf War revealed an alarming deficiency in US defenses. This paper takes a brief look at the major theater missile defense (TMD) systems in use and under development by the US today. Second, it focuses on the performance of the Army's Patriot defense system in the Gulf War. Finally, the paper fulfills its main purpose of offering an in-depth look at the development of the Airborne Laser (ABL) and how it should fit into an overall national structure for TMD.

The paper concludes that Patriot performance in the Gulf war was unsatisfactory, not just because of system flaws, but because of the concept of point defense itself. The ABL provides a unique solution to collateral damage inherent in point defense concepts. In addition, the ABL can provide advanced warning to other theater defense systems in the event of a mass launch which could overtax the ABL's capabilities.

The paper offers several recommendations for the future direction of TMD. First, phase out point defense completely and channel those funds into development of the other TMD systems which minimize collateral damage to the assets they are intended to protect. Second, expedite development of the ABL as the first line of TMD, backed up by long-range theater systems. Third, continue to develop true theater defense systems; that is, systems which have a range of hundreds of kilometers such as the Navy's Aegis and the Army's THAAD systems, preventing TBMs from getting close to their intended target.

Chapter 1

Introduction

> *…the number one lesson [of the war] was that [theater] ballistic missiles are a threat that we don't have the capability to defend against.*
>
> —Gen. Charles A. Horner

The Persian Gulf War of 1990-1991 brought home the reality of the threat of theater ballistic missiles (TBMs) to the American people. Although Scuds and related types of TBMs have existed since the German V-2 of WWII, Desert Storm marked the first time these missiles had been fired at Americans in a consistent campaign. Suddenly, theater missile defense (TMD) became a high priority for the Department of Defense (DOD).

The TBM threat has proliferated into a worldwide problem. Although the Middle East, North Korea, and the People's Republic of China have received the most attention in this area, there are now approximately 8800 TBMs in 32 countries of the world, with 30 new types in development.[1] Notable among these new weapons is the Chinese DF-15, which uses several technological improvements to make interception much more difficult than the Scuds of the Gulf War.[2]

All TBMs have the capability of delivering a deadly array of weapons, including conventional high explosives; nuclear, biological, and chemical (NBC) weapons; and a variety of submunitions.[3] While the US Department of Defense (as well as this paper) is currently focusing primarily on TBMs, the reader should be aware that the scope of TMD

has broadened from the threat of Scuds and their genre to include cruise missiles and unmanned aerial vehicles.

Current DOD doctrine delineates four pillars of TMD. The first pillar is passive missile defense, defined as the measures taken to mitigate the effects of a TMD strike. Typical passive measures include camouflage, decoys, and rapid regeneration of capabilities knocked out by an attack. The second pillar is active defense. This includes the various defense systems in place and on the drawing board designed to destroy TBMs after they have been launched. Third is attack operations, or attempts to stop TBMs before they are launched. F15E strikes against Scud launchers during the Gulf War are an example of the third pillar.

The fourth pillar is Battle Management, Command, Control, Communication, Computers, and Intelligence (BM/C4I). This includes the command and control network which enables all the services, acting jointly, to effectively carry out all aspects of the first three pillars.[4] Because of the limited scope of this paper, the focus will be on the second pillar, or active defense against TBMs.

First, the major TMD systems will be introduced with a limited amount of detail. These systems include both players in the Army's "two-tier" missile defense structure (Patriot and Theater High-Altitude Area Defense, or THAAD), the Navy's Aegis system, and the Air Force's Airborne Laser (ABL). Next, the Patriot missile system's performance in the Gulf War and the development of the emerging ABL will be analyzed more closely. Finally, changes in DOD direction for TMD development will be proposed. These proposals read as follows: (1) phase out land-based "point defense" systems, including Patriot, and channel these funds into development of long-range TMD systems

which will minimize collateral damage; (2) expedite ABL development; and (3) Continue THAAD and Aegis development.

Notes

[1]Report of Ballistic Missile Defense Organization, "1995 Report to the Congress on Ballistic Missile Defense," Air University Library Document no. 44151-3, September, 1995, 2-1.

[2]Michael A. Dornheim, "DF-15 Sophisticated, Hard to Intercept," *Aviation Week and Space Technology* 144, no. 12 (18 March, 1996): 23.

[3]James W. Canaan, "A Compelling National Requirement," Sea Power 38, no. 6 (June 1995): 37.

[4]Robert M. Soofer, "Joint Theater Missile Defense Strategy," *Joint Force Quarterly*, Autumn 1995, 70.

Chapter 2

General Descriptions of Theater Missile Defense Systems

> *No single system or technology can counter the entire spectrum of the theater missile threat.*
>
> —Ballistic Missile Defense Organization's
> 1995 Report to the Congress on Ballistic Missile Defense

Because no single system can counter the TMD threat spectrum, several systems fill that role. The major systems upon which warfighters will depend in future conflicts (the Army's Patriot and THAAD, the Navy's Aegis, and the Air Force's Airborne Laser) will briefly be discussed. A chart of these systems' characteristics is included at the end of this section.

Patriot

The Patriot missile defense system provides "point" defense, constituting the lower tier of the Army's two-tier defense plan. This arrangement is called point defense because Patriot is used to defend specific targets (or points) within a theater. Such targets include military bases, outposts, airfields, and population centers. Patriot is a highly sophisticated, fully integrated system that includes missiles, launchers, radar and command and control. With a detection range of 70 to 90 kilometers, its advanced phased array radar is capable

of tracking 100 targets at the same time or simultaneously managing the intercept engagements of 9 targets.[1]

Patriot can receive cueing information (launch detection, launch position, trajectory information, and predicted impact point) from a number of sources, including airborne in-theater sensors as well as on-orbit sensors.[2] Typically, intercept occurs about 15 to 20 kilometers downrange from the location of Patriot launch.[3]

Originally intended to counter air-breathing threats such as manned or unmanned aircraft, Patriot was quickly pressed into service in the Gulf War to counter the threat of TBMs. One major problem with Patriot discussed later in this paper is the collateral damage inherent in point defense systems. Because of this problem and other performance limitations noted during the war, the Army has stepped up development on PAC-3 (Patriot Advanced Capability, version 3) in an effort to extend Patriot's range and lower its minimum engagement altitude.[4]

THAAD

The Army's upper tier of the two-tier missile defense system is their Theater High-Altitude Area Defense. As the name implies, THAAD is meant to defend an entire theater of military operations from TBM attack. Like Patriot, THAAD will be a fully integrated system, with missiles, launchers, radar, and BM/C4I.[5] It will also receive cueing information from in-theater and on-orbit sensors and will perform tracking with a sophisticated phased-array antenna.[6,7]

Its intercept range is projected to be 200 kilometers, which provides distinct advantages over Patriot.[8] The greatly extended intercept range should prevent much of

the collateral damage seen with Patriot intercepts. In addition, the extended range allows time for additional THAAD launches in case of a miss.

Aegis

The Navy's primary missile defense system was originally conceived in the late 1960's as a shipboard defense to counter Soviet bombers and air-launched cruise missiles. Like the Army's systems, Aegis is a fully integrated system, including ships, radar, missiles, launchers and BM/C4I. The first ship was commissioned in 1983, with 36 ships now serving in this missile defense capacity.[9]

Aegis may currently be described as a sea-based version of the Patriot; i.e., lower tier, or point defense for fleet protection, primarily against Stinger-type missiles. However, the Navy wants to expand Aegis' original mission to include protection of the fleet from TBMs and protection of entire land theaters from the sea (primarily littoral areas).[10] The Ballistic Missile Defense Organization (BMDO) agrees with this vision of naval expansion and is funding them fairly generously (estimated $220M spent in FY95, $284M requested in FY96, $318M programmed for FY97). These numbers represent roughly half the money set aside for each of the Army's major programs.[11]

The Navy's primary reasons for expanding the role of Aegis are based on the forward presence in most of the important regions of the world. In the event of hostilities, the Navy is usually the closest DOD component and the first on station. A TMD capability would allow it to provide cover for troops involved in forcible entry within a few hundred kilometers of coastal regions. Finally, an expanded Aegis mission provides the only plausible TMD for ships at sea or in littoral areas.[12]

Airborne Laser

The Air Force's contribution to the joint TMD mission is the Airborne Laser (ABL). The ABL is designed to destroy TBMs in the boost phase, or within the first couple of minutes after launch. The basic configuration of the ABL weapon system is a megawatt-class chemical laser mounted inside a Boeing 747-400F (wide-bodied freighter version of the 747) flying above 40,000 feet. The ABL would fly a predetermined route, remaining continually on-station in a theater under threat of TBM attack.

In the event of TBM launch, the ABL is capable of autonomous operations, including launch detection, missile tracking, and engagement of TBMs at distances of hundreds of kilometers.[13] This range, plus the ABL's ability to fly near a hostile nation's border, give it an enormous effective range, making it an effective "front-line" defensive weapon.

With an operational prototype scheduled for 2002, three major technical challenges which must be overcome are well on their way to resolution. These are (1) development of a high-energy laser compact enough to fit in a 747-400F, (2) mitigation of atmospheric distortion which weakens the effect of the laser at long distances, and (3) ability to precisely track and point at a moving target from a moving platform at a distance of hundreds of kilometers. The section on ABL development provides more detail on each of these three areas.

A functional ABL provides a major advantage over point defense systems and also enhances theater-wide defense systems. The ability to destroy a TBM in the boost phase causes the warhead as well as resulting missile debris to fall on enemy territory. This advantage is crucial in the defense of population centers. In addition, tracking data

collected by the ABL can be forwarded as cueing information to a theater-wide defense system, in case any TBMs get past the ABL.[14]

Following is a table of capabilities and characteristics of the principal TMD systems which has been compiled from various sources.

Table 1. Summary information of major TMD systems

TMD System	Kill Range (kilometers)	Type of Kill Vehicle	Cueing	Tracking System	Terminal Guidance
Patriot	15 - 20	Blast/frag warhead[15]	Theater/on-orbit sensors	Phased array antenna	Ground radar commands fins[16]
THAAD	200	Kinetic kill[17]	Theater/on-orbit sensors	Phased array antenna	IR seeker on kill vehicle[18]
Aegis	Theater (50 - 200)	Blast/frag warhead[19]	Shipboard/on-orbit sensors[20]	SPY-1B (Phased array antenna)[21]	IR seeker on kill vehicle[22]
Airborne Laser	Hundreds	Laser spot ruptures skin	On-board/on-orbit sensors[23]	On-board active laser tracking	On-board tracking/point-ing system

Notes

[1]Theodore A. Postol, "Lessons of the Gulf War Experience with Patriot," *International Security* 16, no. 3 (Winter 1991/1992): 124.

[2]Report of Ballistic Missile Defense Organization, "1995 Report to the Congress on Ballistic Missile Defense," 2-19.

[3]Postol, "Lessons of the Gulf War," 130-131.

[4]"Patriot PAC-3 Analysis Underway." *Air Defense Artillery*, January-February 1993, 29.

[5]Col. W. Fredrick Kilgore, "THAAD Program Progresses," *Air Defense Artillery*, March-April 1994, 15.

[6]Report of Ballistic Missile Defense Organization, 2-19.

[7]Linda Y. Erickson and Joseph M. Walters, Jr., "Military Specifications and Standards Reform for the Theater High Altitude Area Defense Weapon System," *Army RD & A*, January-February 1996, 20.

[8]Lt Cmdr David R. Desimone, "Theater Missile Defense Beyond Patriot," Air University Library no. M-U 41662 D457t, (Newport, RI, 8 February 1994), 10.

Notes

[9]James W. Canaan, "A Compelling National Requirement," *Sea Power* 38, no. 6 (June 1995): 37.

[10]Lt. Steven C. Sparling, "Ballistic Missile Defense Organization, A Joint Endeavor," *Surface Warfare* 21, no. 2 (March/April 1996): 12.

[11]Report of Ballistic Missile Defense Organization, 5-2 to 5-3.

[12]Scott T. Hutchinson, "Army and Navy Theater Missile Defense: Protecting the Force," *Military Review* LXXV, no. 2 (March-April 1995): 57.

[13]Lt Col Stephen A. Coulombe, "The Airborne Laser: Pie in the Sky or Vision of Future Theater Missile Defense?" *Airpower Journal* VIII, no. 3 (Fall 1994): 62.

[14]John A. Tirpak, "Snapshots of Force Modernization," *Air Force Magazine* 80, no. 2 (February, 1997): 27.

[15]Postol, "Lessons of the Gulf War," 125-126.

[16]Ibid., 130.

[17]Erickson and Walters, "Military Specifications and Standards Reform," 20.

[18]Ibid., 20.

[19]Sparling, "Ballistic Missile Defense Organization, A Joint Endeavor," 8.

[20]Canaan, "A Compelling National Requirement," 40.

[21]Ibid., 37.

[22]Ibid., 39.

[23]Gen. Ronald R. Fogleman, "Theater Ballistic Missile Defense," *Joint Forces Quarterly*, no. 9 (Autumn 1995): 78.

Chapter 3

Patriot Performance in the Persian Gulf War

It is so unlikely that a Scud could hit a fixed target at which it is aimed, that the expenditure of interceptors could hardly improve the survivability of the fixed target.

—Theodore A. Postol, Professor of Science,
Technology, and National Security Policy at MIT

During the period of defense, the number of apartments reported damaged per Scud attack tripled relative to the period when there was no defense.

—Postol

During the Gulf War, the Patriot missile defense system was hailed by the media as a decisive defense against the threat of attack by ballistic missiles. Columnist Patrick Buchanan opined, “Using SDI technology, the United States has shown it can attack and kill ballistic missiles...The (SDI) debate is over.”[1] Others maintain that the death of the ballistic missile threat has been greatly exaggerated. General Colin Powell had reservations about the Patriot performance when he noted, “Sometimes it (Scud) breaks up, breaks it in different pieces, and so you have had cases were the warhead has landed and gone off.”[2] These conflicting views call for an analysis based on observable facts. This chapter will focus on the Patriot system’s performance in the Gulf War based on information from open sources. After examining the Patriot’s effectiveness, we will see

that there are problems not only with Patriot in particular, but also with the entire concept of point defense.

Before discussing the details of the Patriot system's performance, a brief discussion of its intended target is in order; namely, the Scud missile as modified by the Iraqis. Scud is the NATO designation for the SS-1 (DOD designation) missile designed by the Soviets in the 1950s.[3] For etymology buffs, the earliest English meaning of Scud is to run or move quickly. However, a later meaning appears more apt: "to fly too high and off course."[4]

Scud Characteristics

The Iraqi missile was the Al-Hussein, which was a modification of the Scud-B (SS-1C) of early 1960s vintage. Two major modifications were made during the Iran-Iraq war to enable the Iraqis to reach Teheran with their missiles. A midsection was added from other cannibalized Scuds to enlarge the size of the fuel tanks. Another measure to increase range was to decrease the size and weight of the warhead.[5] The Al-Hussein's length of 40 feet is about three and a half feet longer than the Scud-B and increases the flight range from around 300 kilometers to about 600 kilometers.[6]

Although Iraq's best engineers oversaw the modifications, they were either unaware or unconcerned about the resultant negative side effects. The engineering changes greatly increased the missile's range, but it came at a high price. The increased length, combined with the reduced weight of the warhead, moved the center of gravity significantly aft on the missile, reducing Al-Hussein's overall stability and accuracy. The engineers also neglected to strengthen the missile's skin when increasing the length, leading to a significant reduction in buckling strength.[7]

The combination of reduced stability and buckling strength often proved fatal to the missile body. It typically had difficulty remaining aligned to the direction of flight (ending up flying somewhat sideways, like the homemade spears we all made as kids) and often broke apart when entering the dense atmospheric layer at an altitude of 15 to 20 kilometers. This characteristic also became a liability for Patriot because of targeting ambiguity: one Scud produces several pieces which generally look alike to radar, only one piece contains the warhead, and only one piece can be targeted per Patriot missile.[8]

Another Scud-B variant, the Al-Abbas, measured a full 45 feet in length, aggravating the structural and stability problems further. Al-Abbas was used extensively during the Iran-Iraq war, but the Al-Hussein was primarily used during the Gulf War. It is probable that experience demonstrated that problems with Al-Abbas made it virtually unusable.

Al-Hussein's lack of accuracy is notorious. For any given target, Al-Hussein has an equal probability of hitting anywhere within a circle centered on the target with a radius of 1000 meters. Given the fact that the typical Al-Hussein warhead (500 pounds of high explosive) must hit within 10 meters to destroy a hardened target, the chances of destroying a hard target with an Al-Hussein is about 0.00007, or 7 in 100,000. For softer targets, requiring a hit within 30 meters, the chances are still only 0.0006.[9]

According to calculations by Postol, it would take 33,000 Al-Husseins to give a 50% probability of destroying the hardened target. Even though such a large number is highly unlikely, it is probable that a large number of these missiles could be launched against valuable targets. This brings a high cost in terms of Patriot defense because typically two Patriots are launched for every incoming Scud.[10] Passive defenses, such as decoys or mobile facilities, appear to be much more cost-effective than active point defenses.[11]

Patriot Performance

Having seen the characteristics of Scuds, let's turn to the performance of the Patriot missile defense system in the Gulf War. Although reports of Scud engagements vary, between 86 and 91 Scuds were launched during Desert Storm, including about 40 aimed at two cities in Israel, Tel Aviv and Haifa.[12]

No shot-by-shot accounts exist for Scud/Patriot encounters in open literature. The best open-source information regarding the effectiveness of Patriot defense are derived from Israel's detailed civil damage assessments of Scud attacks which document housing damage, bodily injuries, and deaths. According to these assessments, prior to Patriot emplacement 13 unopposed Scuds fell on the Israeli cities with a total of 2698 apartments damaged, 115 people wounded and none killed. After Patriot installation, 14 to 17 Scuds were engaged by the Patriot defenses with 7778 apartments damaged and 168 people wounded. During the time of Patriot defense, one person was killed by direct missile effects, while three died of heart attack. Interviewees claim in non-attribution discussion that the first death mentioned above was due not to a Scud but rather to a Patriot missile hitting the ground.[13]

As we have seen, roughly the same number of Scuds fell in the Israeli cities before and after emplacement of Patriot defenses. However, apartment damage tripled and casualties increased by 46% *after* Patriot was installed. Could the increased damage have resulted from Iraqis honing their aim during the first few missile firings? Probably not, because the Israeli survey ignored Scuds which landed outside the city, causing no damage.

A more likely explanation must begin with the fact that two Patriots were launched for every incoming Scud. This alone gives three times the missiles in the air over the target per Scud launch. Postol lists three possible scenarios which could occur during any Patriot launch. First, the Scud could be destroyed. However, this still leaves open the possibility of damage on the ground from falling pieces. Second, a successful Patriot intercept could merely cut the Scud into many pieces, leaving the warhead unaffected. These pieces and the warhead would then fall to the ground and cause extensive damage.

Third, the Patriot could miss and fall to the ground, or worse, power into the ground with the motor still ignited.[14] This appears to have happened on more than one occasion when a Scud, closing in on its target, required an extremely low intercept angle for the Patriot. According to Postol, "dramatic video-evidence of Patriot interceptors diving into Israeli city streets suggests yet other system failures."[15] These failures clearly include both Patriot's inability to shut off its rocket motor and failure to avoid the damaging explosion of its warhead when diving into friendly territory.

This third scenario in which the Patriot misses its targeted Scud appears to have occurred a significant amount of the time. Reuven Pedatzyr, a missile defense expert at Jaffa Institute for Strategic Studies (Tel Aviv) reports that videotape evidence exists depicting 12 engagements in which the Patriot caused no damage to a Scud. In addition to corroboration of this report by senior Pentagon scientists, the same report was published in *The New York Times* and *Science* magazine. Though these tapes are not in the open literature, the documented reports concerning the existence of the tapes must be given credence. One wonders how Raytheon, Patriot's prime contractor could substantiate their original claims of a 96% hit rate for Patriot in the Gulf War.[16]

Based on Patriot's record against Scuds with conventional warheads, we must conclude that if Scuds had been carrying chemical or biological weapons, there is no indication that Patriot intercepts would have mitigated their intended effects.

To sum up this section on Patriot's performance during the Gulf War and draw conclusions, let's take a last look at the most important facts:

1. Scuds are highly inaccurate.
2. Considerable doubt exists concerning the Patriot's ability to intercept Scuds effectively.
3. Damage on the ground during the period of Patriot's defensive use was three times that of the damage caused by Scuds prior to Patriot employment.

The first fact leads to the conclusion that Patriot is of little value in the defense of small targets, since the Scud would probably miss its intended target anyway. But what about large targets such as population centers? Points (2) and (3) tell us that even if a Patriot does successfully destroy a Scud (which appears doubtful, at least in a number of documented cases), the result of such an engagement greatly increases damage on the ground.

The entire concept of point defense appears to be flawed and other options must be seriously considered for theater missile defense. One option is for the US to do nothing, given Scud's inaccuracy and Patriot's collateral damage. However, in the event of the occasional successful Scud attack, the response that "nothing was done" to prevent it is politically and morally unacceptable. Second, passive measures such as those mentioned earlier could be employed. Applying camouflage, decoys, and mobility to intended Scud targets could cause the enemy to expend far more resources than they otherwise would. This appears to be a very good option for small targets such as military command and

control centers. However, population centers, which appeared to be Scud's primary targets, are difficult to camouflage or move.

Neither of the options listed are satisfactory, so in order to present a credible deterrent to TBMs, more resources must be devoted to other forms of active missile defense. In addition to development of THAAD and expansion of Aegis, the US must expedite development of the ABL, the subject of the next section.

Notes

[1]Editorial, *Washington Times*, 23 January 1991.

[2]Dan Morgan and George Lardner, Jr., "Scud Damage Suggests Patriot Needs Refinement: US Missiles Sometimes Fail to Destroy Iraqi Warheads in Midair Interceptions," *Washington Post*, 21 February 1991, A27.

[3]Bruce A. Smith, "Scud Propulsion Designs Help Patriot System Succeed," *Aviation Week and Space Technology* 134, no. 4 (28 January 1991): 28.

[4]Craig M. Carver, "Word Histories," *The Atlantic Monthly* 267, no. 5 (May 1991): 128.

[5]Postol, "Lessons of the Gulf War Experience with Patriot," 127.

[6]Duncan Lennox, ed., *Jane's Strategic Weapon Systems*, Issue 21 (Sentinel House, Surrey, UK April 1996): no page number.

[7]Postol, "Lessons of the Gulf War Experience with Patriot," 128-129.

[8]Eliot Marshall, "Patriot's Scud Busting Record Is Challenged," *Science* 252, no. 5006 (3 May 1991): 641.

[9]Postol, "Lessons of the Gulf War Experience with Patriot," 168.

[10]Ibid., 145.

[11]Ibid., 168-169.

[12]Ibid., 140.

[13]Ibid.

[14]Marshall, "Patriot's Scud Busting Record Is Challenged," 641.

[15]Postol, "Lessons of the Gulf War Experience with Patriot," 170.

[16]Eliot Marshall, "Patriot's Effectiveness Challenged," *News & Comment* 254, no. 5033 (8 November 1991): 791.

Chapter 4

Airborne Laser—Theater Missile Defense for Boost Phase

> *The Airborne Laser revolutionizes our operational concepts, tactics, and strategies.*
>
> —Air Force Secretary Sheila E. Widnall
>
> *From what I've seen, the airborne laser could be in the same league as the invention of stealth, the development of Global Positioning Satellites, and the Manhattan Project.*
>
> —Widnall

The Airborne Laser (ABL) is the Air Force's primary contribution to active defense against theater ballistic missiles (TBMs). With the speed and accuracy of laser technology, the ABL is the embodiment of precision engagement, one of the four operational concepts of General Shalikashvili's Joint Vision 2010.[1] The ABL can genuinely be classified as a modern revolution in military affairs, where advanced laser technology has been applied to current military needs in a complete package, including hardware, training, and tactics.

As a boost phase weapon, one of its advantages over point defense is immediately obvious—lack of collateral damage. Debris from the destroyed Scud along with the warhead falls on enemy territory instead of the intended target. Another advantage to early TBM engagement is that if a TBM gets through the ABL defense system, accurate

information on its trajectory can immediately be sent to the next layer of TMD with sufficient time for subsequent engagement.

Before the ABL becomes a reality, three major technical hurdles must be overcome to ensure its success. They are (1) a laser powerful enough to destroy a TBM, yet compact enough to fit on a Boeing 747-400F; (2) an optical system capable of shaping the laser beam to correct for atmospheric distortion; and (3) a tracking and pointing system accurate enough to keep the laser spot on a target moving at about 1500 meters per second at a distance of hundreds of kilometers.

This section will focus on the recent progress made in each of these areas and how they will contribute to a credible weapon for TMD.

Laser Development

First, how can a laser "destroy" a TBM? As a non-explosive weapon, the laser cannot literally blow a TBM out of the sky, but it exploits some of the missile's own characteristics to make the kill. In the boost phase, a Scud's fuel tanks are pressurized in order to force fuel from the tanks through the plumbing and injectors and into the combustion chamber. This tank pressure plus the Scud's thin skin (about two millimeters) make it very vulnerable to a hot laser spot during boost phase. Two destruction modes are possible (1) vent, which is the gradual development of a crack or rip, and (2) burst, which is the sudden and catastrophic rupture of the tank.

With either the vent or burst, the remaining fuel escapes, causing the engines to shut down. In addition, the missile body loses its structural integrity and tends to buckle. From that point, friction and gravity quickly combine to bring the remainder of the missile

to the ground. Theater ballistic missiles fueled by solid propellant are predicted to behave in a similar manner as liquid-fueled missiles under high-power laser illumination.[2]

These concepts on modes of TBM destruction were proven during two separate tests at White Sands Missile Range (WSMR), New Mexico in October, 1993. A one-megawatt laser (Mid-InfraRed Advanced Chemical Laser, or MIRACL) at the High Energy Laser System Test Facility was used to destroy a number of pressurized tanks which simulated Scuds. In each test the MIRACL laser and its associated optics were used to rapidly target and destroy several tanks which were sized and pressurized differently. The tests conclusively demonstrated a laser's ability to destroy a TBM as well as the capability to retarget quickly in a multiple-launch situation. Numerous ruptured tanks displayed conspicuously around the ABL System Program Office bear mute testimony to the ability of a laser to destroy Scuds.

The MIRACL was capable of destroying pressurized tanks, but can a megawatt-class laser plus its requisite chemical fuels be made to fit on a Boeing 747-400F, the platform of choice for the ABL contractor team? According to the TRW corporation, they have already solved the most critical portion of that problem. On 6 August 1996, TRW scientists reported a successful demonstration of their laser prototype slated for use on the ABL. Their Chemical Oxygen-Iodine Laser (COIL) generated several hundred kilowatts with a high degree of efficiency high enough, in fact to allow the 747-400F to carry sufficient chemical reactants to satisfy the single-mission requirement of 40 engagements of 3 to 5 seconds each.[3] In order to achieve power in the megawatt range, several of these COIL units may be connected in series inside the 747.

Other experiments at the Phillips Laboratory have demonstrated the ability of a laser-equipped airborne platform to destroy active missiles. Tests conducted in the early 1980s with 1970s technology proved the concept when a precursor to the ABL, the Airborne Laser Laboratory, fired on and destroyed AIM-9B air-to-air missiles. It also shot down a number of simulated maritime cruise missiles.[4] There should be no confusion—this experiment did not come close to the requirements of the ABL: the laser was far less powerful and the range was only five to ten kilometers.[5] However, the fact that a boosting missile could be destroyed from a laser on an airborne platform was clearly demonstrated.

Adaptive Optics or Atmospheric Compensation Development

The second major challenge in the development of the Airborne Laser is to get a high-energy laser beam from the ABL to a TBM hundreds of kilometers away with sufficient power to cause structural failure by either venting or bursting the tank. Without a system to compensate for the deleterious effects of the atmosphere, very little of the energy from even a megawatt-class laser would reach such a distant target.

Atmospheric distortion of a laser beam (or any other form of energy propagated through the air) arises from thermal variations in the air. These variations cause the atmosphere to behave like a bad piece of optical glass, distorting the image as light passes through. To the naked eye, the effect is most noticeable when viewing the stars as they "twinkle" at night or when looking at "wavy" distant objects over a hot surface.[6]

The early 1980s witnessed a scientific breakthrough called adaptive optics which revolutionized scientists' ability to mitigate these atmospheric distortions and record

precise images of distant objects. First used to make images of heavenly bodies, its military uses quickly became obvious. For example, it has been used by the Air Force to record accurate satellite images, and now it will be applied to the ABL.

The heart of the adaptive optics system is a deformable or "rubber" mirror, which is a flexible reflecting surface set on an array of small, movable pistons. A telescope collects light which depicts the distorted image of a distant target object and the deformable mirror corrects the image. But since the atmospheric temperatures and resultant turbulence fluctuate continually, the adaptive optics system must also operate continually, not only determining the nature and intensity of atmospheric distortions but also calculating and performing the corrections necessary to maintain a good image.[7] For more details concerning adaptive optics, please refer to Appendix A.

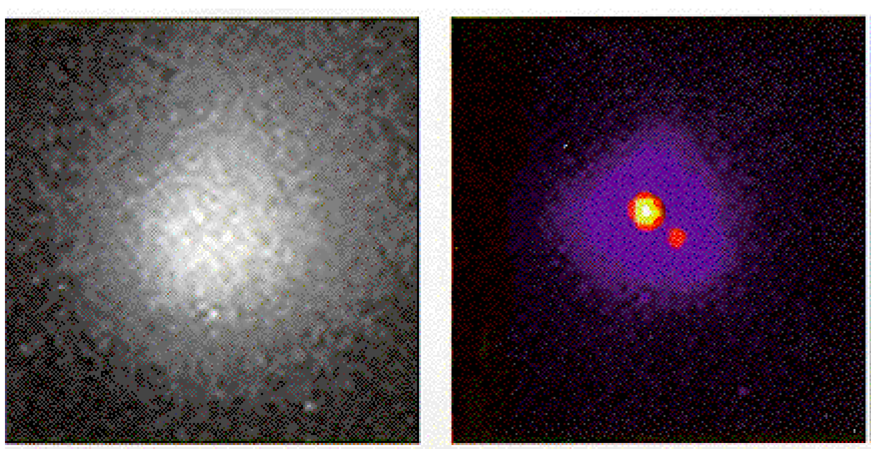

Figure 1. Uncompensated (left) and compensated (right) images of Beta Delphini star system (Photo used by permission)

This method has been used to achieve dramatically improved images of numerous objects in space, as evidenced by Figure 1 which depicts two images of the binary star Beta Delphini. The first, resembling a circular smear of light, is the uncompensated image

taken by a 1.5 meter telescope, and the second, revealing two stars, is the image taken by the same telescope with the adaptive optics system engaged.[8]

Ground-based adaptive optics systems operate through 90 vertical kilometers of atmosphere, where the worst turbulence is concentrated in the first twenty kilometers. The ABL has a much more stressing challenge: it must operate at a range of hundreds of kilometers horizontally through the atmosphere. Because of the ABL's challenging operational scenario, considerable doubt existed concerning the ability of an adaptive optics system to correct for that amount of turbulence. For this reason, the Airborne Laser Extended Atmospheric Characterization Experiment (ABLE ACE), an $18M laser propagation experiment was designed and performed. Its purpose was to characterize the upper atmosphere (the ABL's operating regime) and to test the feasibility of the ABL concept.

The experiment involved two aircraft on parallel flight paths at nearly identical altitudes ranging from 35,000 to 50,000 feet and separation distances of 20 to 200 kilometers. The transmitter aircraft was equipped with a pulsed laser of known characteristics. During flight, this laser was aimed at the receiver aircraft equipped with an optical bench containing ten separate experiments to determine how the atmosphere affected the incoming laser light.

The ABLE ACE experiment was flown by the Lasers and Imaging Directorate, Phillips Laboratory, Kirtland AFB, from March to June 1995 following two years of concept development and hardware development, integration, and validation. After 124 flying hours during 28 flights followed by thousands of hours of data reduction, ABLE ACE determined the upper atmosphere does not deviate significantly from predicted

characteristics. Therefore the long, horizontal atmospheric paths through which the ABL must operate should not hinder its performance. In addition, computer codes which had previously been used to simulate the atmosphere were successfully validated.[9]

More importantly, the findings of ABLE ACE helped convince DOD planners and budgeters in the Pentagon of the potential of the ABL as a weapon system. As a result the ABL has been granted $1.2B for system development and Secretary Widnall and Chief of Staff Gen. Fogleman have given their solid support for the ABL program. For their efforts the ABLE ACE team won Air Force Materiel Command's Science and Technology Achievement Award for 1995, the Command's highest science award.

We have seen that current laser technology provides a laser capable of generating energy in the megawatt range which can fit on a Boeing 747-400F. Adaptive optics systems will allow the laser beam to reach the target TBM with sufficient energy to destroy it. But in order to hold the laser spot on a TBM, a final challenge must be overcome. Operating from a rolling, pitching, and yawing airborne platform moving at hundreds of kilometers per hour, the ABL must precisely track and point a laser at a TBM moving at 1500 meters per second.

Tracking and pointing

Clearly, normal tracking methods are not up to the tracking and pointing scenario given above. Radar systems lack the necessary precision to perform such a feat. Infrared tracking is more precise, but it relies on a heat source. During the boost phase, the hot rocket plume dominates everything else in the sky (except the sun), but this presents a couple of problems. First, the plume characteristics such as size and shape are continually

changing. This presents a poor foundation upon which to base a pointing system at ABL distances. In addition, when the motor burns out, the plume disappears, and along with it goes the infrared tracker's performance.

To satisfy the ABL's tracking demands, scientists turned once more to applications of laser technology and employed a method known as active laser tracking (or active tracking). Like radar, active tracking sends out a signal and uses the return signal from the target to perform tracking.[10] For more details on the ABL's active tracking system, please refer to Appendix A.

The active tracking method was successfully demonstrated at White Sands Missile Range on 3 June and 16 June, 1996. A team of scientists and engineers from Phillips Laboratory using ground-based equipment tracked a TBM at a distance of 50 km traveling at 1000 meters per second. This first-ever successful active track of a boosting missile was the highest precision tracking of airborne object ever achieved.[11] In recognition of their accomplishment the Phillips Laboratory team was awarded AFMC's Science and Technology Achievement Award for 1996.

The effort to improve upon and integrate these experimental methods is continuing at the Phillips Laboratory. The latest experiment will combine the technologies of adaptive optics and active tracking in an effort to demonstrate tracking through longer distances and heavier turbulence.

Despite the recent encouraging breakthroughs and demonstrations, much work remains to be done. All the systems must be mounted and tested on an airborne platform. Systems must move from performance in tens or hundreds of hertz to the kilohertz range. The systems must prove workable at an altitude of 45,000 feet. However, all three

technologies critical to the development of the ABL, the high-energy laser, the adaptive optics system, and high precision tracking and pointing have been demonstrated and are being improved upon, keeping the ABL on track for a working prototype by 2002.

Notes

[1]Gen John M. Shalikashvili, "Joint Vision 2010," : 1.

[2]Dr Paul H. Merritt, Airborne Laser Technology Division, interviewed by author, 15 November 1996.

[3]Michael A. Dornheim, "TRW Demonstrates Airborne Laser Module," *Aviation Week and Space Technology* 145, no. 8 (19 August 1996): 22.

[4]Lt Col Stephen A. Coulombe, "The Airborne Laser: Pie in the Sky or Vision of Future Theater Missile Defense?" *Airpower Journal* VIII, no. 3 (Fall 1994): 60.

[5] Lt Col Shawn O'Keefe, Airborne Laser Technology Division, interviewed by author, 11 March 1997.

[6]Robert Q. Fugate and Walter J. Wild, "Untwinkling the Stars - Part I," *Sky & Telescope* 87, no. 5 (May 1994): 25.

[7]Ibid., 26.

[8]Ibid., 29.

[9]D.C. Washburn, et al, "Airborne Laser Extended Atmospheric Characterization Experiment," Air University Library no. M-U 43954-4 (Final Report, May 1996): 15-2.

[10]Maj Gerald W. Wirsig, "Airborne Laser Moves Closer to Reality," *Kirtland Focus*, 28 June 1996.

[11]Wirsig, "Airborne Laser Moves Closer to Reality."

Chapter 5

Recommendations

> *BP Boost Phase Intercept weapons will contribute to a layered defense against theater ballistic missiles.*
>
> —Gen. Ronald R. Fogleman

Given the current proliferation of theater ballistic missiles, a diverse, multilevel theater missile defense system is essential to counter the TBM threat. In the aftermath of the Gulf War, the Patriot missile was acclaimed as the key player in TMD. A closer examination of Patriot's performance calls that contention into question. Serious problems have been revealed, not just for the Patriot, but for the entire concept of point defense. Furthermore, recent technological advances have been explored by all the military service components, providing other options for TMD. In view of the failure of point defense and the advent of recent innovations, the following options should be carefully considered.

(1) Phase out reliance on point defense systems such as Patriot as soon as possible. Patriots are not required to defend small targets because of the Scud's inaccuracy. On the other hand, when Patriot batteries were employed to defend larger targets such as cities, damage to ground structures tripled. Therefore, the US must be committed to boost phase and long-range intercepts to avoid this collateral damage. The funds saved by the point defense phase-out should be redistributed to other TMD systems.

(2) Expedite the development and extensive deployment of the ABL. Boost phase kills are critical for eliminating damage to friendly people and assets. An effective ABL would form the first line of defense, with long-range TMD providing the second line. This arrangement would replace the concept of THAAD as the "upper tier" with Patriot as the "lower tier."

(3) Continue ongoing development of long-range sea- and land-based TMD. The US must possess the capability to destroy TBMs at long range to minimize collateral damage. The Navy's forward presence makes it first on the scene in most regions of the world. It is therefore essential that their Aegis system have the capability to provide a shield against TBMs in instances which require forcible entry of US troops into regional hotspots. Normally situated on international waters, Aegis is free from potentially problematic land-basing considerations.

In addition, the Army must continue development of THAAD. Land-based defenses are ultimately essential for defending land-based assets. If the fleet's Aegis battery is concentrating on defending itself against maritime cruise missiles, it may not be able to simultaneously defend assets on the ground. Therefore, the knowledge and experience gained with Patriot should be used by the Army as the basis for creating a workable long-range system to protect the assets in their area of responsibility.

The threat of TBMs will overshadow the theater of future conflicts. DOD must develop a cost-efficient, cost-effective defense to this threat. In view of the questionable utility of point defense provided by Patriot and the emergence of the ABL, the US must revise its current concept of TMD. Any future TMD structure should include the ABL as

its first line of defense, with an expanded Aegis and THAAD forming the second line. Further resources should not be expended on the Patriot's point defense.

Appendix A

Adaptive Optics

ABL operators must have good information about what the atmospheric conditions are before they can correct for them. Where does the information on how to clean up the image come from? For a ground-based laser which images space objects, complete information for the entire optical path through the atmosphere is necessary to get the best images possible. Therefore, scientists use a laser to illuminate and excite a sodium layer 90 km above earth (getting virtually all the atmosphere and its distortion in the path). These excited sodium ions then emit photons in a predictable way and can therefore be used as a simulated beacon of light at the furthest reaches of the atmosphere.[1]

Back on the ground, a telescope collects the light from the excited sodium layer after the light has traveled down through the atmosphere, and the image is compared to an undistorted "ideal" image. The information from this comparison is then used to adjust the deformable mirror and correct the distortion. As mentioned above, because the atmosphere is continually fluctuating in temperature and resultant turbulence, this process must be repeated many times per second in order to maintain a proper image of the object. In fact, the ABL's adaptive optics system will have to operate in the kilohertz range, or thousands of times per second.

Active Tracking

Initially, the ABL will pick up the launch and initial boost of a TBM with an onboard IR scanner, which will look down from the ABL and rotate through the entire 360 degree field of view.[2] This will eliminate complete dependence on cueing from outside sources, although the ABL will be capable of receiving cueing information from other sensors, such as those on orbit.

After TBM launch detection, the ABL will initially perform coarse tracking on the target with an IR tracker. This method will provide accurate enough tracking to hit the TBM with a relatively low-power illuminating laser, whose spot will cover approximately half of the TBM. This spot will then be moved forward until it reaches the forward edge of the missile. The illuminating beam is held on the forward edge to perform fine tracking of the missile. The forward edge is also used as a reference point: the high-energy laser is pointed back from the forward edge a predetermined amount in order to hit the pressurized fuel tanks.

Notes

[1]Robert Q. Fugate and Walter J. Wild, "Untwinkling the Stars - Part I," *Sky & Telescope* 87, no. 5 (May 1994): 28.

[2]Gen. Ronald R. Fogleman, "Theater Ballistic Missile Defense," *Joint Forces Quarterly*, no. 9 (Autumn 1995): 78.

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